US006831456B2

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(12) **United States Patent**
Doescher

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(45) **Date of Patent: Dec. 14, 2004**

(54) **ANGLE SENSOR AND METHOD OF INCREASING THE ANISOTROPIC FIELD STRENGTH OF A SENSOR UNIT OF AN ANGLE SENSOR**

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(73) Assignee: **Koninklijke Philips Electronics N.V.**, Eindhoven (NL)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/120,681**

(22) Filed: **Apr. 11, 2002**

(65) **Prior Publication Data**

US 2002/0149358 A1 Oct. 17, 2002

(30) **Foreign Application Priority Data**

Apr. 14, 2001 (DE) 101 18 650

(51) **Int. Cl.**[7] **G01R 33/09**; G01B 7/30
(52) **U.S. Cl.** **324/207.21**; 324/252; 324/207.25
(58) **Field of Search** .... 324/207.12, 207.22, 324/207.21, 207.2, 207.26, 252, 251, 207.25; 73/514.31, 717, 728, 862.69, 862.673; 338/32 R; 428/692; 702/156, 152

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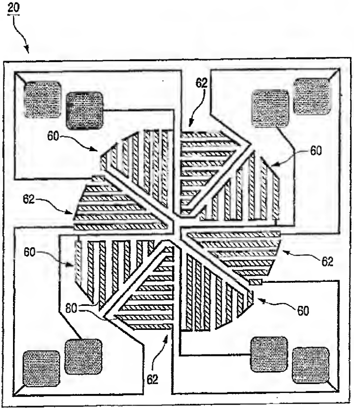
(57) **ABSTRACT**

The invention relates to an angle sensor comprising at least two angle-offset anisotropic magnetoresistive sensor units comprising anisotropic magnetoresistive elements, in which the angle sensor comprises at least a device for increasing the anisotropic field strength of the sensor units. The invention also relates to a method of increasing the anisotropic field strength of a sensor unit of an angle sensor comprising magnetoresistive elements, in which a magnetic supporting field present in a preferred direction of the magnetoresistive elements is generated.

37 Claims, 7 Drawing Sheets



comprises the two sensor units (**40, 42** see FIG. **1**), in which each sensor unit comprises MR elements **60** and **62**, respectively.

The MR elements **60, 62** of the two sensor units comprise anisotropic magnetoresistive strips (MR strips) **80** which are arranged always parallel to each other within each MR element **60, 62**.

In the embodiment of the angle sensor **20** shown in FIG. **2**, Barber pole structures with opposite inclination of the Barber pole in oblique parts of the resistive bridges are realized but the sensor may of course also be made without Barber poles. Both sensor units or bridges are rotated 90° with respect to each other and are interlaced.

Embodiments of MR elements according to the invention, which may be used in angle sensors and are shown in FIGS. **1** and **2**, will now be described with reference to the following Figures.

FIG. **3** is a plan view of an MR element **64** provided with MR strips **82**. In this embodiment, a coil **100**, which substantially completely surrounds the MR element **64**, is used as a device for increasing the anisotropic field strength of the MR element.

The shape of the coil **100** is particularly visible in FIG. **3***b* in which the MR element **64** can be clearly seen in a cross-section and has a surface on which the MR strips **82** have been provided. The coil **100** substantially completely surrounds the MR element **64**.

Although the coil cross-section is shown rectangularly in this case, it may also assume any other arbitrary geometrical shape, for example, also a circular cross-section.

The coil **100** generates a substantially homogeneous magnetic field in the core, which field is denoted by the arrow H. The magnetic field is aligned substantially parallel to the longitudinal alignment of the MR strips which corresponds to the preferred direction of the MR strips. The MR strips of the embodiment shown in FIG. **3** have a thickness d of 120 nm and a width b of 6 μm so that a ratio $V=d/b=2*10^{-2}$ is realized.

FIG. **4** shows a further embodiment of an MR element according to the invention. FIG. **4***a* is a plan view of an MR element **66** which, likewise as the element shown in FIG. **3***a*, also has longitudinal MR strips **84**.

Instead of the coil surrounding the MR element, internal coils **120** are provided in this embodiment. The structure of an internal coil **120** is particularly clear from FIG. **4***b* in which the magnetic field H generated by the coil or the coils **120** substantially corresponds to the magnetic field H as is also generated in the embodiment shown in FIG. **3**.

The coils **120** are thin-film coils integrated in the layout, so that the dimensions of the MR elements with the coils can be clearly reduced with respect to the dimensions of the embodiment shown in FIG. **3**. The MR strips of the embodiment shown in FIG. **4** have a thickness d of 120 nm and a width b of 6 μm so that a ratio $V=d/b=2*10^{-2}$ is realized.

FIG. **5** shows a further embodiment of an MR element according to the invention. In this embodiment, the MR element **68** is provided on a permanent magnet **140** with a north pole N and a south pole S. Also in this embodiment, the magnet **140** generates a magnetic field H which is aligned in the direction of the MR strips **86** and the preferred direction of the MR element.

FIG. **5***b* is a side elevation of the embodiment shown in FIG. **5***a*, in which the structural form and the arrangement of the MR element **68** on the surface of the magnet **140** is clearly visible.

The embodiment shown in FIG. **5** is more voluminous as compared with the embodiment shown in FIG. **4** but this embodiment can be manufactured at low cost and is very reliable because of the relative insensitivity of the magnet. The MR strips in the embodiment shown in FIG. **5** have a thickness d of 180 nm and a width b of 6 μm so that a ratio $V=d/b=3*10^{-2}$ is realized.

FIG. **6** shows a further embodiment of an MR element according to the invention. The MR element **70** is substantially analog to the MR elements shown in FIGS. **3** to **5**, and in this embodiment MR strips **88** are also arranged in the preferred direction of the MR element **70**.

As is particularly clear from FIG. **6***b*, a hard-magnetic layer **160** is provided on the surface of the MR element **70** and above the MR strips **88** in this embodiment. This hard magnetic layer **160** also generates a magnetic field H in the preferred direction, analogously to the embodiments described hereinbefore.

It is to be noted that the embodiments shown only represent examples of possible MR elements and possible devices for increasing the anisotropic field strength of the sensor units, but those skilled in the art will be able to conceive further modifications within the scope of the invention, and can particularly combine partial elements of the embodiments shown.

The MR strips (**80, 82, 84, 86, 88**) are diagrammatically shown as lines only in FIGS. **3** to **6**. The geometrical design may however, be varied in accordance with the invention, which is particularly shown in FIG. **7**. The MR strips of the embodiment shown in FIG. **6** have a thickness d of 160 nm and a width b of 4 μm, so that a ratio $V=d/b=4*10^{-2}$ is realized.

FIG. **7***a* shows an MR strip **90** which is rectangular and has a length l in the preferred direction and a width b. FIG. **7***b* shows a further possible embodiment of an MR strip **92** which has a hyperboloid shape, whereas the MR strip **94** shown in FIG. **7***c* has an asteroidal shape.

The aspect ratio between length l and width b should be chosen to be as large as possible so as to achieve a high anisotropic field strength, and is in a range between 50 and 200 in the embodiment shown. A particularly preferred aspect ratio is about 100.

The characteristic features of the invention disclosed in the foregoing description, the drawings and the claims may be essential both individually and in an arbitrary combination for realizing the invention in its various embodiments.

What is claimed is:

1. A system comprising an angle sensor for measuring an angle comprising:

at least two angle-offset anisotropic magnetoresistive sensor units comprising anisotropic magnetoresistive elements, wherein the angle sensor has a 360 degree period and further comprises at least a device for increasing an anisotropic field strength of the sensor units to such an extent that the anisotropic field strength is higher than a field strength in an environment in which the sensor is used, and, an apparatus for generating said field strength in said environment.

2. A system as claimed in claim **1**, wherein the device for increasing the anisotropic field strength comprises at least a coil arrangement.

3. A system as claimed in claim **2**, wherein the coil arrangement comprises at least an external coil per magnetoresistive element which substantially surrounds the magnetoresistive element.

4. A system as claimed in claim **2**, wherein the coil arrangement comprises at least a thin-film coil integrated in the layout of each magnetoresistive element.

5. A system as claimed claim **1**, wherein the device for increasing the anisotropic field strength comprises at least a magnet.

6. A system as claimed in claim 5, wherein the magnet is a permanent magnet.

7. A system as claimed in claim 1, wherein at least the magnetoresistive element comprises a hard-magnetic layer provided thereon.

8. A system as claimed in claim 1, wherein the at least two angle-offset sensor units have an angle offset of 90°.

9. A system as claimed in claim 1, wherein the magnetoresistive elements comprise magnetoresistive layers of a predetermined length l, width b and thickness d, in which the ratio V between the thickness d and the width b has a value $V \geqq 4*10^{-3}$.

10. A system as claimed in claim 9, wherein at least one of the magnetoresistive layers has a rectangular, hyperboloid or asteroidal shape.

11. A system as claimed in claim 1, wherein at least one of the magnetoresistive layers consists of a material from the following group: NiCo 50:50, NiCo 70:30, CoFeB 72:8:20, NiFe 8 1:19.

12. A system as claimed claim 1, wherein it further comprises a means for applying magnetic reversal pulses.

13. A system as claimed in claim 12, wherein the means for applying magnetic reversal pulses comprises at least a coil arrangement.

14. A system as claimed in claim 12, wherein the means for applying magnetic reversal pulses compensates a spontaneous reversal of magnetism.

15. A system as claimed in claim 1, wherein it further comprises subsequently arranged or integrated signal electronics.

16. A system as claimed in claim 1, wherein the magnetoresistive elements comprise magnetoresistive layers, which have a substantially hyperboloid or asteroidal shape.

17. A method of increasing an anisotropic field strength of a sensor unit of an angle sensor comprising magnetoresistive elements, wherein a magnetic supporting field (H) present in a preferred direction of the magnetoresistive elements is generated to such an extent that the anisotropic field strength is higher than a field strength in an environment in which the sensor is used, said method further comprising generating the field in said environment, and said sensor unit has a 360 degree period.

18. A method as claimed in claim 17, wherein the magnetic supporting field (H) is generated permanently or discontinuously.

19. A method as claimed in claim 17, wherein the supporting field (H) is generated by at least a coil arrangement.

20. A method as claimed in claim 17, wherein the supporting field (H) is generated by a magnet.

21. A method as claimed in claim 17, wherein the supporting field (H) is generated by a hard magnetic layer which is provided on at least one of the magnetoresistive elements.

22. A method as claimed in claim 17, wherein the magnetoresistive elements are built up of magnetoresistive layers, in which the magnetoresistive layers are given a substantially hyperboloid or asteroidal shape.

23. An angle sensor comprising at least two angle-offset anisotropic magnetoresistive sensor units comprising anisotropic magnetoresistive elements, wherein the angle sensor comprises at least a device for increasing the anisotropic field strength of the sensor units, wherein the magnetoresistive elements comprise magnetoresistive layers of a predetermined length l, width b and thickness d, in which the ratio V between the thickness d and the width b has a value $V \geqq 4*10^{-3}$.

24. An angle sensor as claimed in claim 23, wherein at least one of the magnetoresistive layers has a rectangular, hyperboloid or asteroidal shape.

25. An angle sensor as claimed in claim 23, wherein the device for increasing the anisotropic field strength comprises at least a coil arrangement.

26. An angle sensor as claimed in claim 25, wherein the coil arrangement comprises at least an external coil per magnetoresistive element, which substantially surrounds the magnetoresistive element.

27. An angle sensor as claimed in claim 26, wherein the coil arrangement comprises at least a thin-film coil integrated in the layout of each magnetoresistive element.

28. An angle sensor as claimed in claim 23, wherein the coil arrangement comprises at least a thin-film coil integrated in the layout of each magnetoresistive element.

29. An angle sensor as claimed in claim 23, wherein the device for increasing the anisotropic field strength comprises at least a magnet.

30. An angle sensor as claimed in claim 29, wherein the magnet is a permanent magnet.

31. An angle sensor as claimed in claim 23, wherein at least the magnetorèsistive element comprises a hard-magnetic layer provided thereon.

32. An angle sensor as claimed in claim 23, wherein the at least two angle-offset units have an offset angle of 90°.

33. An angle sensor as claimed in claim 23, wherein at least one of the magnetoresistive layers consist of a material from the following group: NiCo 50:50, NiCo7O:30, CoFeB 72:8:20, NiFe 81:19.

34. An angle sensor as claimed in claim 23, wherein it further comprises a means for applying magnetic reversal pulses.

35. An angle sensor as claimed in claim 34, wherein the means for applying magnetic reversal pulses comprises at least a coil arrangement.

36. An angle sensor as claimed in claim 34, wherein the means for applying magnetic reversal pulses compensates a spontaneous reversal of magnetism.

37. An angle sensor as claimed in claim 23, wherein it further comprises subsequently arranged or integrated signal electronics.

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US006844999B2

p1 of 2

(12) United States Patent
Wang et al.

(10) **Patent No.: US 6,844,999 B2**
(45) **Date of Patent: Jan. 18, 2005**

(54) **BORON DOPED COFE FOR GMR FREE LAYER**

(75) Inventors: **Hui-Chuan Wang**, Pleasanton, CA (US); **Chyu-Jiuh Torng**, Pleasanton, CA (US); **Yun-Fei Li**, Fremont, CA (US)

(73) Assignee: **Headway Technologies, Inc.**, Milpitas, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 164 days.

(21) Appl. No.: **10/238,768**

(22) Filed: **Sep. 10, 2002**

(65) **Prior Publication Data**

US 2004/0047086 A1 Mar. 11, 2004

(51) **Int. Cl.**[7] **G11B 5/127**; G11B 5/33
(52) **U.S. Cl.** **360/324.12**
(58) **Field of Search** 360/324.1, 324.11, 360/324.12

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Kanai et al., IEEE Trans. on Magnetics, vol. 33, No. 5, Sep. 1997, pp. 2872–2874.

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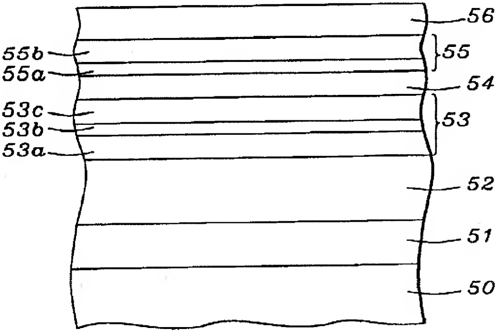
Primary Examiner—George Letscher
Assistant Examiner—Christopher R. Magee
(74) *Attorney, Agent, or Firm*—George O. Saile; Stephen B. Ackerman

(57) **ABSTRACT**

Prior art gains in GMR ratio resulting from use of NiFeCr as a seed layer were offset by the resulting high values obtained for H_c and H_k. This problem has been overcome by combining a seed layer of NiCr or NiFeCr with a free layer of boron doped CoFe. Additionally, when using a synthetic pinned layer, further improvement is achieved by using boron doped CoFe for the two antiparallel layers.

28 Claims, 2 Drawing Sheets



DESCRIPTION OF THE PREFERRED EMBODIMENTS

The key features of the present invention are:

(1) A single layer of boron doped CoFe is used for the free layer

(2) The two ferromagnetic layers that make up the synthetically pinned layer are also boron doped CoFe.

The relevant magnetic characteristics of boron doped CoFe are shown in the hysteresis curves seen in FIGS. **2**, **3**, and **4**. These are for films of CoFe containing 5 atomic % of boron, said films being respectively 5, 10, and 15 Angstroms thick. Curves **21**, **31**, and **41** were taken along the easy axis while curves **22**, **32**, and **42** were taken along the hard axis. Data extracted from these curves (as well as from FIG. **1**) are summarized in TABLE I below:

TABLE I

Free layer	Thickness (Å)	H_c (Oe)	H_k (Oe)	GMR ratio (%)
CoFe	5	7.90	6.53	11.27
B-doped CoFe	5	4.66	3.33	11.19
B-doped CoFe	10	4.66	3.37	12.29
B-doped CoFe	15	5.80	4.25	11.66

This data makes it clear that the substitution of boron doped CoFe for undoped CoFe leaves the GMR ratio essentially unchanged while significantly reducing both H_c and H_k. It is also noteworthy that these quantities are relatively insensitive to film thickness. We can also apply the same principle to the pinned layer. Thus, due to the intrinsic magnetic softness and anisotropy of CoFeBx, if the two antiparallel components of a synthetically pinned layer are made of boron doped CoFe, the associated antiferromagnetic material (such as MnPt, MnPtPd) will have much better pinning properties, such as smaller H_{opin} compared to pure CoFe.

We now present a detailed description of the process of the present invention. In the course of so doing, the structure of the invention will also become apparent:

Referring now to FIG. **5**, the process begins with the provision of substrate **50** (such as alumina) and depositing thereon seed layer **51** that is either NiCr or NiFeCr, as discussed earlier. This is followed by the deposition of antiferromagnetic layer **52**. Next, pinned layer **53** is deposited. As mentioned earlier, it is commonly a trilayer of two soft ferromagnetic layers (**53***a* and **53***c*) separated by a layer of an antiferromag-netic coupling material such as ruthenium (layer **53***b*). Layers **53***a* and **53***c* are heated and annealed under suitable conditions so that they end up being magnetized in anti-parallel directions. Layers **53***a* and **53***c* each contains between about 50 and 90 atomic % cobalt, between about 5 and 30 atomic % iron, and between about 3 and 20 atomic % boron.

Deposition of non-magnetic spacer layer **54** (typically copper) now follows, after which free layer **55***a* is laid down. A key feature of the invention is that this layer is boron doped CoFe. This free layer contains between about 70 and 90 atomic % cobalt, between about 5 and 10 atomic % iron, and between about 3 and 20 atomic % boron. Optionally, NiFe layer **55***b* may be deposited over layer **55***a* but this is not essential for the successful operation of the finished device. The addition of layer **55***b* leads to a slight improvement in H_c and H_k at the cost of a slightly smaller GMR value for the same moment.

The process of the present invention concludes with the deposition of capping layer **56** (usually tantalum) on the free layer.

A key benefit of devices formed as described above, is that, as noted earlier, the free layer can have a thickness that is in the range of from about 15 to 100 Angstroms since its coercivity over that thickness range will vary by less than about 10%. Typically, the coercivity is found to be between about 2 and 5 Oersted with an anisotropy field that is between about 3 and 5 Oersted. Furthermore, the inter-layer coupling between the free layer and the pinned layer is less than about 10 Oersted. These favorable performance parameters are achieved while still retaining a GMR ratio that is between about 10 and 15%.

What is claimed is:

1. A process to manufacture a bottom spin valve, comprising:

providing a substrate and depositing thereon a seed layer that contains Ni and Cr;

depositing an antiferromagnetic layer on said seed layer;

depositing a pinned layer on said antiferromagnetic layer;

depositing a non-magnetic spacer layer on said pinned layer;

on said non-magnetic spacer layer, depositing a free layer consisting of boron doped cobalt-iron, interlayer coupling between said free layer and said pinned layer being less than about 10 Oersted; and

depositing a capping layer on said free layer.

2. The process described in claim **1** wherein said seed layer is elected from the group consisting of NiCr and NiFeCr.

3. The process described in claim **1** wherein the step of depositing said pinned layer further comprises depositing a layer of ruthenium between two layers of boron doped cobalt-iron and then magnetizing said layers of boron doped cobalt-iron in opposing directions.

4. The process described in claim **3** wherein said two layers of boron doped cobalt-iron each contains between about 50 and 90 atomic % cobalt, between about 5 and 30 atomic % iron, and between about 3 and 20 atomic % boron.

5. The process described in claim **3** further comprising depositing a layer of NiFe between said free layer and said capping layer.

6. The process described in claim 1 wherein said free layer contains between about 70 and 90 atomic % cobalt, between about 5 and 10 atomic % iron, and between about 3 and 20 atomic % boron.

7. The process described in claim 1 wherein said free layer has a thickness that is in the range of from about 15 to 100 Angstroms and a coercivity that varies by less than about 10% over said thickness range.

8. The process described in claim 1 wherein said free layer has coercivity that is between about 2 and 5 Oersted.

9. The process described in claim 1 wherein said free layer has an anisotropy field that is between about 3 and 5 Oersted.

10. The process described in claim **1** wherein said spin valve ha a GMR ratio that is between about 10 and 15%.

11. The process described in claim 1 wherein said spin valve has a seed layer that is NiCr and a GMR ratio that is between about 10 and 15% and a free layer having a coercivity that is between about 2 and 5 Oersted and said free layer has an anisotropy field between about 3 and 5 Oersted.

12. The process described in claim **1** wherein said spin valve has a seed layer that is NiFeCr and a GMR ratio that is between about 10 and 15% and free layer having a coercivity that is between about 2 and 5 Oersted and said free layer has an anisotropy field between about 3 and 5 Oersted.

L23 ANSWER 15 OF 22 INSPEC (C) 2010 IET on STN

TITLE: Thermomagnetic analysis of the (FexCo1-x)80B20 **amorphous** ribbons

AUTHOR: Tejedor, M.; Fernandez, A.; Perez, M.J. (Dept. de Fisica, Fac. de Ciencias, Oviedo Univ., Spain); Madurga, V.

SOURCE: Physica Status Solidi A (16 Jan. 1993), vol.135, no.1, p. 283-8, 8 refs.
ISSN: 0031-8965
DOCUMENT TYPE: Journal
TREATMENT CODE: Experimental
COUNTRY: Germany
LANGUAGE: English

AB Metallic glass samples of **(FexCo1-x)80B20** are studied by thermomagnetic analysis. The results show that this ternary alloy can be considered as a mixture of the binary alloys Fe80B20 and Co80B20 with their compositions changed slightly in the way of a little increase in the boron content in the FeB alloy. This is justified by the greater size of the Fe atoms that provide more interstitial space for B. This increase in B, increases the average exchange interaction that explain the properties observed

L11 ANSWER 4 OF 28 INSPEC (C) 2010 IET on STN

TITLE: A simple model of giant magneto-impedance effect in **amorphous** thin films

AUTHOR: Chengyuan Dong; Shipu Chen; Hsu, T.Y.; Xu Zuyao (Sch. of Mater. Sci. & Eng., Shanghai Jiao Tong Univ., China)

SOURCE: Journal of Magnetism and Magnetic Materials (Sept. 2002), vol.250, no.1-3, p. 288-94, 19 refs.
ISSN: 0304-8853
Published by: Elsevier, Netherlands
DOCUMENT TYPE: Journal
TREATMENT CODE: Theoretical
COUNTRY: Netherlands
LANGUAGE: English

AB A simple model of giant magneto-impedance (GMI) effect in **amorphous** thin films is proposed and the expressions of effective permeability and impedance are derived in the frame of classical electrodynamics and ferromagnetism. The dependence of GMI effect on the external magnetostatic field and the frequency of alternating current is discussed in the viewpoint of the energy conversion in the film. Numerical simulation is conducted and the calculated GMI effect shows reasonable consistency with that measured on a **(CoFe)80B20 amorphous** film

L11 ANSWER 11 OF 28 INSPEC (C) 2010 IET on STN

TITLE: Fabrication of exchange-biased spin valves with CoFeB **amorphous** layers

AUTHOR: Feng, T.; Childress, J.R. (Dept. of Mater. Sci. & Eng., Florida Univ., Gainesville, FL, USA)

SOURCE: Journal of Applied Physics (15 April 1999), vol.85, no.8, p. 4937-9, 5 refs.
ISSN: 0021-8979
Published by: AIP, USA
Conference: 43rd Annual Conference on Magnetism and Magnetic Materials, Miami, FL, USA, 9-12 Nov. 1998
DOCUMENT TYPE: Conference; Conference Article; Journal
TREATMENT CODE: Experimental
COUNTRY: United States
LANGUAGE: English

AB **Amorphous Co72Fe8B20** is a soft ferromagnetic material with a high electrical resistivity and is, therefore, unique for use as the active layer in giant magnetoresistance (GMR) spin-valve structures. CoFeB/Cu/CoFeB/FeMn spin-valve structures were prepared by magnetron sputtering with varying FeMn thickness, deposition sequence, CoFeB deposition rate, Cu deposition rate, applied magnetic field, and annealing treatment, and their magnetic and magnetotransport properties were investigated by superconducting quantum interference device magnetometry and four-terminal magnetoresistance measurements. FeMn, above a critical thickness of 100 A, is found to be a suitable biasing layer only if deposited on top of CoFeB. Optimum CoFeB and Cu thicknesses and deposition rates were also determined. A modest GMR ratio of 1.2% in a field range 10 Oe<H<15 Oe is achieved at T=10 K in a CoFeB (40 A)/Cu(30 A)/CoFeB(20 A)/FeMn(100 A) structure. However, we expect that the size of the GMR effect can be tailored independently by suitable engineering of the CoFeB/Cu interface

L11 ANSWER 25 OF 28 INSPEC (C) 2010 IET on STN

TITLE: Electrical resistivity of liquid-quenched **amorphous** alloys

AUTHOR: Naqvi, S.M.M.R.; Rizvi, S.D.H. (Dept. of Phys., Karachi Univ., Pakistan); Raza, S.M.; Gormani, M.A.; Farooqui, N.

SOURCE: Modern Physics Letters B (20 Feb. 1995), vol.9, no.3-4, p. 195-200, 6 refs.ISSN: 0217-9849
DOCUMENT TYPE: Journal
TREATMENT CODE: Experimental
COUNTRY: Singapore
LANGUAGE: English

AB Electrical resistivity measurements of **amorphous (FezCo100-z)83B17** alloys in the temperature range 40 K<T<300 K have been obtained. We observed from the analysis of the resistivity data that there is no s-d interaction or Js-d coupling. An empirical relationship for estimating ΘD is suggested from the normalized electrical resistivity data, which holds good both for theoretical and estimated ΘD. For s-d interaction or Js-d coupling to occur in ferromagnetic amorphous alloys, **ordering** of ferromagnetic domains, i.e. Heisenberg interaction in a disordered matrix, would require temperatures of T≤ΘD/50.simeq.0.02 ΘD

L23 ANSWER 4 OF 22 INSPEC (C) 2010 IET on STN

TITLE: Magnetic and structural properties of FeCoB thin films

AUTHOR: Platt, C.L.; Minor, N.K.; Klemmer, T.J. (Seagate Technol., Pittsburgh, PA, USA)

SOURCE: IEEE Transactions on Magnetics (July 2001), vol.37, no.4, pt.1, p. 2302-4, 7 refs.
ISSN: 0018-9464
Published by: IEEE, USA
Conference: Eighth Joint Magnetism and Magnetic Materials Intermag Conference, San Antonio, TX, USA, 7-11 Jan. 2001
COUNTRY: United States
LANGUAGE: English

AB The magnetic and structural properties of FeCoB thin films as a function of boron content have been investigated for applications requiring soft, high moment materials. The films were either co-sputtered from separate FeCo-35 and B targets or from a **(Fe65Co35)90B10** alloy target. A peak in the coercivity was observed for small amounts of boron. Measurements of coercivity with fields applied along the radial and circumferential directions of the Si wafer showed isotropic magnetic behavior. The coercivity and saturation induction decreased with increasing amounts of boron above 2 atomic%. High angle X-ray diffraction showed a broadening of the (110) peak with increasing boron, indicative of either increased microstrains or smaller average grain size perpendicular to the film. The (110) peak, however, did not shift with added boron, suggesting that on average the boron does not expand the FeCo lattice. The drop in coercivity around 10 atomic% B was identified with a transition to a primarily **amorphous** state. Since these alloys have a high positive magnetostriction, their magnetic properties are particularly sensitive to film stress/strain. Using sputtering gas pressure as a variable, differences in coercivity were also correlated with changes in film strain

L23 ANSWER 13 OF 22 INSPEC (C) 2010 IET on STN

TITLE: Effect of tensile stress-annealing on the magnetical behaviour of some thin **amorphous** ribbons for fluxgate sensors

AUTHOR: Diaconu, E.D.; Chiriac, H. (Nat. Inst. of Res. & Dev. for Tech. Phys., Iasi, Romania); Hoffmann, H.; Ioan, C.; Moldovanu, C.; Macoviciuc, M.

SOURCE: Materials Science Forum (1998), vol.287-288, p. 437-40, 12 refs.
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DOCUMENT TYPE: Conference; Conference Article; Journal
LANGUAGE: English

AB The influence of tensile stress annealing on magnetic properties of the low magnetostrictive **Co68.25Fe4.5Si12.25B15 amorphous** ribbons has been studied experimentally in order to obtain very good quality cores for fluxgate sensors. A hard ribbon axis anisotropy can be induced in the ribbon exposed to a 1 h pre-annealing at 340°C followed by 1 h stress-annealing at the same temperature with applied longitudinal tensile stress greater than 380 MPa. The obtained results are discussed in terms of the magnetization processes, which take place in the ribbon. The measured functional parameters of the developed sensors prove that by suitable treatments, the studied **amorphous** ribbon can be used as magnetic sensing element for improved fluxgate sensors

L23 ANSWER 14 OF 22 INSPEC (C) 2010 IET on STN

TITLE: An **amorphous** magnetic bimetallic sensor material

AUTHOR: Kraus, L.; Haslar, V.; Zaveta, K.; Pokorny, J. (Inst. of Phys., Czechoslovak Acad. of Sci., Prague, Czech Republic); Duhaj, P.; Polak, C.

SOURCE: Journal of Applied Physics (15 Nov. 1995), vol.78, no.10, p. 6157-64, 10 refs.
ISSN: 0021-8979
DOCUMENT TYPE: Journal
TREATMENT CODE: Experimental
COUNTRY: United States
LANGUAGE: English

AB An **amorphous** bimetal ribbon consisting of magnetostrictive (Fe40Ni40B20) and nonmagnetostrictive **(Co67Fe4Cr7Si8B12)** layers was prepared by planar flow casting from a double-chamber crucible. The effect of applied tensile stress on hysteresis loops and the surface domain structures of the stress-relieved bimetal was investigated at room temperature. The hysteresis loops can be well explained by superpositions of hysteresis loops of the individual layers. Only the magnetostrictive layer is responsible for the influence of applied stress on magnetic behavior. At a certain stress, the magnetic anisotropy of the magnetostrictive layer abruptly changes from a hard-ribbon-axis to an easy-ribbon-axis type. This transition is accompanied by a change of domain structure and a sharp maximum of the coercive field. A simple model taking into account an interplay of the applied tensile stress with the compressive stress produced by thermal contraction after stress relief and/or by bending of the ribbon has been developed. The observed behavior can be well explained by the model

L23 ANSWER 19 OF 22 INSPEC (C) 2010 IET on STN

TITLE: Perpendicular magnetic recording media of **amorphous** (Fe4Co6)80B20 ultrafine particle films

AUTHOR: Kunimoto, A. (Dept. of Res. & Dev. for New Mater., Riken Corp., Tokyo, Japan); Kato, M.; Masuda, T.; Ohnuma, S.; Masumoto, T.

SOURCE: IEEE Transactions on Magnetics (Sept. 1987), vol.MAG-23, no.5, pt.1, p. 2803-5, 7 refs.
ISSN: 0018-9464
Conference: INTERMAG '87: International Magnetics Conference, Tokyo, Japan, 14-17 April 1987
DOCUMENT TYPE: Conference; Conference Article; Journal
TREATMENT CODE: Application; Practical; Experimental
COUNTRY: United States
LANGUAGE: English

AB **Amorphous (Fe4Co6)80B20** ultrafine particles (UFP) formed on a substrate by sputtering exhibit high coercive force and large perpendicular magnetic anisotropy. The material having those magnetic properties basically can be applied to perpendicular recording media. A double layer coating of polymer and AlN on the ultrafine particles resulted in good mechanical properties of the media such as upright standing of each particle and durability of the coating. There were almost no changes in magnetic properties between before and after coating the UFP. Magnetic recording characteristics of the UFP film were evaluated and it was found that the UFP film was perpendicularly recorded. Subsequent annealing of the UFP film at around 450°C brought on considerable improvement of the magnetic properties, increasing magnetization, coercive force and magnetic anisotropy. Dipulse ratio obtained was about 0.45 for coating thickness of 0.2 μm

L23 ANSWER 22 OF 22 INSPEC (C) 2010 IET on STN

TITLE: Study of the origin of the magnetic anisotropy in RF sequential co-sputtered Co100-xBx and **Co74Fe6B20** thin films

AUTHOR: Kim, D.Y.; Walser, R.M. (Dept. of Electr. & Comput. Eng., Texas Univ., Austin, TX, USA)

SOURCE: Rapidly Solidified Alloys and Their Mechanical and Magnetic Properties, 1986, p. 173-6 of xv+463 pp., 8 refs.
Editor(s): Giessen, B.C.; Polk, D.E.; Taub, A.I.
ISBN: 0 931837 23 5
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Conference: Rapidly Solidified Alloys and Their Mechanical and Magnetic Properties, Boston, MA, USA, 2-4 Dec. 1985
Sponsor(s): Mater. Res. Soc
DOCUMENT TYPE: Conference; Conference Article
TREATMENT CODE: Experimental
COUNTRY: United States
LANGUAGE: English

AB The authors prepared thin, **amorphous**, compositionally modulated films (CMF) by RF sequential co-sputtering with Co, B, and Fe targets. In principle this technique can produce controlled, small (<15 A) scale modulations in composition. The in-plane anisotropies and coercivities of the CMF were more than one magnitude larger than those of typical thin, homogeneous, amorphous, **alloy** films (AF). The increase in anisotropy was growth induced and could be reduced by annealing to values comparable to those of amorphous **AF**. The coercivity, however, could not be significantly decreased by annealing, except in CMF with the highest boron concentration. The stability of the coercivity might, therefore, be an observable consequence of the small scale composition heterogeneity

L32 ANSWER 2 OF 15 INSPEC (C) 2010 IET on STN

TITLE: Soft magnetic properties of Co-based **amorphous alloys** with wide supercooled liquid region

AUTHOR: Itoi, T.; Inoue, A. (Inst. of Mater. Res., Tohoku Univ., Sendai, Japan)

SOURCE: Materials Transactions, JIM (July 1998), vol.39, no.7, p. 762-8, 22 refs.
CODEN: TJIMAA, ISSN: 0916-1821
Published by: Japan Inst. Metals, Japan
DOCUMENT TYPE: Journal
TREATMENT CODE: Experimental
COUNTRY: Japan
LANGUAGE: English

AB New Co-based **amorphous alloys** with a wide supercooled liquid region above 40 K before crystallization and good soft magnetic properties were synthesized in the Co72-xFexZr8B20 and Co63Fe7Zr10-xMxB20 (M=Nb, Ta or W) systems. The supercooled liquid region defined by the difference between crystallization temperature (Tx) and glass transition temperature (Tg), ΔTx(=Tx-Tg), is 39 K for Co56Fe16Zr8B20, 45 K for Co63Fe7Zr6M10B20, 40 K for Co63Fe7Zr4Ta6B20 and 44 K for Co63Fe7Zr6W4B20. The glass transition is also observed for the Co63Fe7M10B20 (M=Ta or W) alloys. The Co-based **amorphous alloys** with ΔTx above 40 K exhibit low coercivity of 2.5 to 5.6 A/m, low magnetostriction of 1.7+10-6 to 3.0+10-6 and high permeability (μe) of

10000 to 23000 at 1 kHz. The good μe characteristics are maintained in a high frequency range and the μe at 1 MHz is 5700 for Co56Fe16Zr8B20 and 6800 for Co63Fe7Zr6Ta4B20. The high frequency permeability is superior to those for conventional Co- and Fe-based **amorphous alloys**. The electrical resistivity (ρn) is as high as 1.7 to 2.0 μΩm and hence the reduction of eddy current loss caused by the high ρn is presumed to be the origin of the better high-frequency permeability. The simultaneous achievements of good soft magnetic properties and high ρn are presumably due to the formation of a unique amorphous structure in which two kinds of atomic pairs of metal-metal (Co-Fe-Zr-M) and metal-metalloid (**Co-Fe** -Zr-M-**B**) types are homogeneously mixed on a subnanoscale, because the former type pair has good soft magnetic properties and the latter type pair has high ρn. The good combination of high stability of the supercooled liquid and good soft magnetic properties is expected to induce future development as a new type of soft magnetic bulk **amorphous alloy**

L32 ANSWER 10 OF 15 INSPEC (C) 2010 IET on STN

TITLE: Anisotropic **magnetoresistance** in transition metal-boron **amorphous alloys**

AUTHOR: Yamasaki, J.; Fukunaga, H.; Narita, K. (Dept. of Electrical Engng., Kyushu Univ., Fukuoka, Japan)

SOURCE: Journal of Applied Physics (March 1981), vol.52, no.3, pt.2, p. 2202-4, 12 refs.
ISSN: 0021-8979
Conference: Twenty-Sixth Annual Conference on Magnetism and Magnetic Materials, Dallas, TX, USA, 11-14 Nov. 1980
Sponsor(s): AIP; IEEE

DOCUMENT TYPE: Conference; Conference Article; Journal
TREATMENT CODE: Experimental
COUNTRY: United States
LANGUAGE: English

AB Anisotropic **magnetoresistance** ratio (AMR) was measured for binary and ternary (**Fe**, **Co**, Ni)-**B**
amorphous alloys over the temperature range from 77K to room temperature varying the composition systematically. The largest AMR at room temperature was 0.45% for **(Fe0.95Co0.05)84B16** alloy, which is smaller by about one order in magnitude than those in crystalline binary transition metal alloys. It was found that AMR in Co-Ni-B alloys exhibits a maximum similar to crystalline Co-Ni alloys. The maximum values were obtained for the alloys having magnetic moment of 0.56 μB regardless of composition, meaning that the rigid band model is applicable to the anisotropic **magnetoresistance** in Co-Ni-B **amorphous alloys**

L32 ANSWER 11 OF 15 INSPEC (C) 2010 IET on STN

TITLE: Metallic **magnetic head** materials

AUTHOR: Radeloff, C. (Vacuumschmelze GmbH, Hanau, West Germany)

SOURCE: NTG-Fachberichte (1980), vol.76, p. 31-7, 39 refs.
CODEN: NTGFDK, ISSN: 0341-0196
Conference: Conference on Magnetic Materials and Components in Communications Engineering and Data Transmission, Bad Nauheim, West Germany, 16-18 April 1980

DOCUMENT TYPE: Conference; Conference Article; Journal
TREATMENT CODE: General Review
COUNTRY: Germany, Federal Republic of
LANGUAGE: German

AB The choice of the recording head materials depends on the type of the recording surface (gamma-Fe_2O_3, CrO_2, metal pigment) and the application (record or replay). Recording heads for oxide surfaces shall have at least 0.4 T saturation field, for metallic surfaces 0.8 T. Replay heads shall have high initial permeability. The desirable magnetic and mechanical properties of head materials are tabulated, the composition of permalloy-type materials (NiFeCuMo) and the effects of various additives (Nb, Ta, Ti, Al) on hardness, permeability and saturation field are discussed. The Si-Al-Fe alloy, known as SENDUST seems to be the ideal material for metal-pigment surfaces. SENDUST lamination are now produced but manufacturing costs are high, and it is doubtful whether SENDUST lamination will be commercially available. Other **amorphous alloys** (**Co**, Ni, **Fe**)70-80 (**B**, Si)30-20 have high initial permeability, hardness of 900 and 0.5 to 0.8 T saturation field

NiFe/CoFeB Spin-Valve Heads For Over 5 Gbit/in^2 Density Recording

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Abstract **— This paper outlines the successful use of NiFe/$(Co_{90}Fe_{10})_{100-x}B_x$ (x = 5, 10%) for soft magnetic, thermally stabilized spin-valves. The GMR effect in the NiFe/CoFeB spin-valve increases after annealing. The annealing effect of CoFeB on CoFeB/Cu interfaces is investigated by high resolution TEM-EDX analysis. Merged inductive NiFe/CoFeB spin-valve heads with a read gap length of 0.18 μm and a write gap length of 0.28 μm having NiO(400Å)/NiFe(10Å)/$CoFeB_5$(10Å)/Cu(32Å)/ $CoFeB_5$(20Å)/Ta(100Å) spin-valve film and high Bs laminated FeZrN/NiFe top poles were fabricated. Their read/write performance were tested on a low noise $CoCr_{19}Pt_5Ta_2Nb_2$ thin-film disk with an Mrt of 0.6 memu/cm^2 and a coercivity of 2600 Oe. A normalized output per track-width of 1000 μVpp/μm and a 50% rolloff linear density (D_{50}) of 182 kFCI is obtained. This performance well exceeds the performance of 5 Gbit/in^2 spin-valve heads. The measured S/N was 26.8 dB for a spin-valve head with with a narrow read track-width of 0.68 μm, and the feasibility of 8 G bit/in^2 recording density is studied using a 1/7 code Narrow Band PRML channel.**

I. INTRODUCTION

Spin-valve heads are very attractive for use as future high density recording MR heads because of their high readback output voltages, linear response, and symmetrical read sensitivity profiles. In a previous work, we reported on the high field sensitivity NiFe/CoFe spin-valve heads with soft magnetic NiFe/$Co_{90}Fe_{10}$ free layers, and demonstrated a 5 Gbit/in^2 density recording performance in combination with a low noise CoCrPtTa thin-film disk [1]. The NiFe/CoFe spin-valve heads, however, suffered from a thermal reduction problem in the GMR output after the annealing process during wafer fabrication.

In this paper, we report on an improvement in the thermal stability of spin-valve films using NiFe/$(Co_{90}Fe_{10})_{100-x}B_x$ layers (an addition of B to $Co_{90}Fe_{10}$). We investigate the annealing effect of CoFeB on CoFeB/Cu interfaces by high resolution TEM-EDX analysis and consider the mechanism of the enhanced GMR of the NiFe/CoFeB spin-valve after annealing. Then, we fabricate and test inductive/spin-valve heads having a NiFe/CoFeB spin-valve film and a high Bs FeZrN/NiFe magnetic pole, and discuss the performance of over 5 Gbit/in^2 density recording.

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II. SPIN-VALVE FILMS

Spin-valve film samples with structures of NiFe/$(Co_{90}Fe_{10})_{100-x}B_x$/Cu/$(Co_{90}Fe_{10})_{100-x}B_x$/NiFe/FeMn and NiO/NiFe/$(Co_{90}Fe_{10})_{100-x}B_x$/Cu/$(Co_{90}Fe_{10})_{100-x}B_x$/NiFe were deposited on glass substrates using a magnetron sputtering system with a DC in-plain magnetic field of about 80 Oe. FeMn and NiO antiferromagnetic films were used as a pinning layer. The base pressure was less than 5×10^{-5} Pa. The sputtering pressure for NiO was 0.06 Pa. The argon sputtering pressure was 0.3 Pa, except for the NiO. The spin-valve film samples were annealed for three hours in applied transverse fields of 2500 Oe along their easy-axis. MR response curves were measured along the easy-axis using a in-line four point probe with applied magnetic fields of ± 1 kOe.

Figure 1 shows a comparison of GMR ratio dependence on annealing temperature between the spin-valve film samples of NiFe/CoFe and NiFe/CoFeB layers. Sample (a) has a structure of NiFe(35Å)/CoFe(40Å)/Cu(32Å)/ CoFe(40Å)/FeMn(100Å) with CoFe. Samples (b) and (c) have structures of NiFe(35Å)/$CoFeB_{10}$(40Å)/Cu(32Å)/ $CoFeB_{10}$(30Å)/NiFe(10Å)/FeMn(100Å) with $CoFeB_{10}$ and NiO(500Å)/$CoFeB_5$(40Å)/Cu(32Å)/$CoFeB_5$(20Å)/NiFe(55Å) /Ta(100Å) with $CoFeB_5$, respectively. The GMR output for the CoFe sample (a) without B decreases after annealing at over 230°C. Note, however, that the GMR output for the CoFeB samples (b) and (c) increases with an increase of

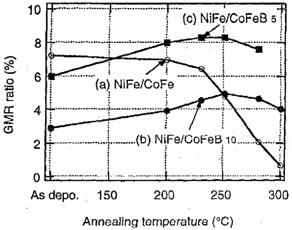

Fig. 1 Annealing temperature dependence of GMR ratio in spin-valve films with NiFe/CoFe and NiFe/CoFeB.
(a) Ta(50Å)/NiFe(35Å)/CoFe(40Å)/Cu(32Å)/CoFe(40Å)/FeMn(100Å)/Ta(100Å).
(b) Ta(50Å)/NiFe(35Å)/$CoFeB_{10}$(40Å)/Cu(32Å)/$CoFeB_{10}$(30Å)/NiFe(10Å)/ FeMn(100Å)/Ta(100Å).
(c) NiO(500Å)/$CoFeB_5$(40Å)/Cu(32Å)/$CoFeB_5$(20Å)/NiFe(55Å)/Ta(100Å).

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Fabrication of exchange-biased spin valves with CoFeB amorphous layers

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Amorphous $Co_{72}Fe_8B_{20}$ is a soft ferromagnetic material with a high electrical resistivity and is, therefore, unique for use as the active layer in giant magnetoresistance (GMR) spin-valve structures. CoFeB/Cu/CoFeB/FeMn spin-valve structures were prepared by magnetron sputtering with varying FeMn thickness, deposition sequence, CoFeB deposition rate, Cu deposition rate, applied magnetic field, and annealing treatment, and their magnetic and magnetotransport properties were investigated by superconducting quantum interference device magnetometry and four-terminal magnetoresistance measurements. FeMn, above a critical thickness of 100 Å, is found to be a suitable biasing layer only if deposited on top of CoFeB. Optimum CoFeB and Cu thicknesses and deposition rates were also determined. A modest GMR ratio of 1.2% in a field range $10\,\mathrm{Oe} < H < 15\,\mathrm{Oe}$ is achieved at $T = 10\,\mathrm{K}$ in a CoFeB (40 Å)/Cu(30 Å)/CoFeB(20 Å)/FeMn(100 Å) structure. However, we expect that the size of the GMR effect can be tailored independently by suitable engineering of the CoFeB/Cu interface. © *1999 American Institute of Physics.* [S0021-8979(99)64108-1]

I. INTRODUCTION

Amorphous magnetic thin films have been paid increasing attention for applications to giant magnetoresistance (GMR) spin-valve structures due to their low coercivity and high electrical resistivity. Amorphous magnetic materials can achieve lower coercivities than permalloy $Ni_{80}Fe_{20}$, which is commonly used as the soft ferromagnetic sensing layer in spin-valve multilayers. Coercivities of 0.7 Oe have been obtained in amorphous CoFeB films.[1] Furthermore, the high resistivity of amorphous magnetic materials results in a larger resistance change and, consequently, higher output signal for a given GMR ratio. Also, amorphous magnetic layers can potentially increase the GMR effect by minimizing current shunting through under layers and cap layers. Typically, the resistivity of amorphous CoFeB can be as high as 40 $\mu\Omega\,\mathrm{cm}$.[2] Amorphous CoFeB spin-valve multilayers with a NiO exchange-biasing layer have been reported.[2] FeMn, another typical antiferromagnet for exchange biasing, has been extensively used in NiFe spin-valve multilayers.[3] Therefore, it is a worthwhile comparison to study amorphous CoFeB spin valves with FeMn-biasing layers. In this article, structures of the type CoFeB/Cu/CoFeB/FeMn were investigated for their magnetic and magnetotransport properties. While the primary interest in CoFeB resides in its low coercivity and lack of magnetocrystalline anisotropy at room temperature, the present study focuses on the properties of this system at $T = 10\,\mathrm{K}$, in order to investigate fundamental aspects of deposition, magnetic interactions, and the relationship between structural and magnetotransport properties.

II. EXPERIMENT

All CoFeB spin-valve multilayer samples were prepared in a magnetron sputtering system with a base pressure of 1×10^{-8} Torr and argon plasma pressure of 2 mTorr, and deposited on oxidized silicon substrates. The CoFeB target composition was $Co_{72}Fe_8B_{20}$ at. % at which the magnetostriction value is close to zero at room temperature and, consequently, stress anisotropy is eliminated. The FeMn target was $Fe_{50}Mn_{50}$ at. % and no buffer or cap layers were used. As amorphous materials are metastable solids, a cooled substrate and high deposition rate are believed to be essential to their deposition.[4] However, our x-ray diffraction measurements indicate that amorphous CoFeB was sustained for deposition rates as low as 0.34 Å/s using room-temperature substrates. An induced uniaxial anisotropy was realized by applying a static magnetic field of about 600 Oe in the plane of the film during deposition and annealing. The hysteresis loops at $T = 10\,\mathrm{K}$ were obtained in a superconducting quantum interference device magnetometer and the magnetoresistance measurements were obtained with a standard four-terminal method.

III. EXPERIMENTAL RESULTS

Generally, the coercivity of crystalline magnetic films increases with decreasing thickness due to the increased influence of surface and interface defects on the magnetic reversal. In the case of multilayered amorphous CoFeB films, the interface "defects" may consist of crystalline or microcrystalline regions which are formed at the CoFeB/Cu or CoFeB/FeMn interfaces. For CoFeB/Cu/CoFeB/FeMn structures, soft magnetic properties are required for the free CoFeB layer only, while the pinned CoFeB layer may be more coercive, and the use of CoFeB for both layers is driven by the goal of increasing the overall resistivity. In our case, with $t(\mathrm{Cu}) = 100\,\mathrm{Å}$, the free-layer coercivity H_c at $T = 10\,\mathrm{K}$ is found to be constant and smaller than the absolute accuracy of our magnetometer (a few Oe) down to layer thickness t of 50 Å. Below 50 Å, the coercive field increases sharply, to about 20 Oe for $t = 30\,\mathrm{Å}$ and 40 Oe for $t = 20\,\mathrm{Å}$. Consequently, we usually chose our minimum free-layer thickness to be 40 Å, so that its coercivity is less than

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